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Research on MPPT Control of Photovoltaic Cells based on the Combination of Conductance Increment Method and Fuzzy Control

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Abstract

The most important part of photovoltaic power generation system is solar photovoltaic cell. Aiming at the unsatisfactory dynamic and steady performance of tracking maximum power point by traditional conductance increment method, a tracking method based on conductance increment method and fuzzy control is proposed. According to the mathematical model of photovoltaic cell, this method is modeled on MATLAB/Simulink platform, and it is concluded that there is a unique maximum power point in the output power of photovoltaic cell under certain external conditions, and compared with conventional conductance increment method by simulation. By comparing the results, it is concluded that the combined algorithm has faster tracking speed and smaller error when reaching the maximum power point than the conductance increment method when the external illumination intensity changes.

Keywords

Photovoltaic Power Generation System; Maximum Power Point; Conductance Increment Method; Fuzzy Control.

1. Introduction

Due to the vigorous development and utilization of fossil energy in modern society, the existing energy is about to be exhausted, and the burning of gases emitted by fossil energy such as carbon dioxide and sulfur dioxide will cause environmental problems such as greenhouse effect and acid rain. In order to solve the problems of energy and environmental protection, scholars all over the world have devoted themselves to finding new green energy sources that can replace fossil energy, and solar energy has become the best substitute for fossil energy such as coal and oil because of its easy access and large irradiation range. Although sunlight is easy to obtain, the efficiency of converting the radiant energy of the sun into electric energy is not ideal, which is easy to cause waste of resources. Therefore, it is particularly important to improve the conversion efficiency of solar photovoltaic cells.

Considering that the output power of solar photovoltaic cells is affected by light intensity and temperature, it is of great significance to study how to make solar photovoltaic cells work at the maximum power point (MPPT) all the time. In this paper, MPPT control algorithm based on the combination of conductance increment method and fuzzy control is used to improve the dynamic performance and steady-state performance of maximum power point tracking.

2. Photovoltaic cell modeling

2.1 Mathematical model of photovoltaic cells[1]

In the picture, I_{ph} is the Photoproduction current in the photovoltaic cell, I_D is that dark current inside the photovoltaic cell, R_{sh} is the equivalent bypass resistance inside the photovoltaic cell, R_s

is the equivalent series resistance inside the photovoltaic cell, I_L is the output load current of the photovoltaic cell; R_L is the equivalent output resistance of photovoltaic cell.

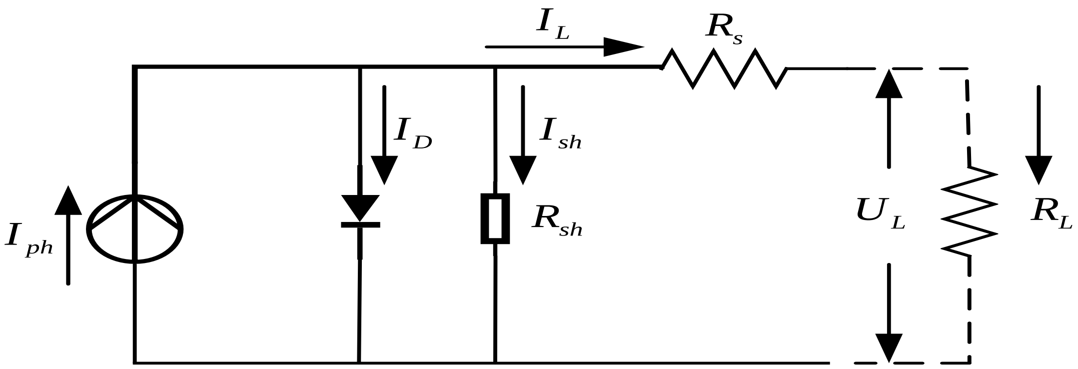

Figure 1. Equivalent circuit diagram of photovoltaic cell

I_{ph} is proportional to the light receiving area of the photovoltaic cell and the illumination intensity of the incident light of the sun, U_L is the output voltage of photovoltaic cell, define U_{oc} to be the open circuit voltage of the photovoltaic cell equivalent circuit, I_m to be the current at the maximum power point of the photovoltaic cell, U_m to be the voltage at the maximum power point of the photovoltaic cell, then the output current of the photovoltaic cell ,the expression is[2]:

$$I_L = I_{ph}\{1 - C_1\,[\exp(\frac{U_L}{C_2 U_{oc}}) - 1]\} \tag{1}$$

Among them,

$$C_1 = (1 - \frac{I_m}{I_{ph}})\,exp(\frac{-V}{C_2 U_{oc}}) \tag{2}$$

$$C_2 = (\frac{U_m}{U_{oc}} - 1)[ln(1 - \frac{I_m}{I_{ph}})]^{-1} \tag{3}$$

Considering the changes of light intensity and temperature in the actual environment, the output characteristic formula of photovoltaic cells is as follows.

$$DI = \alpha \cdot R/R_{\mathrm{ref}} \cdot DT + (R/R_{\mathrm{ref}} - 1) \cdot I_{ph} \tag{4}$$

$$DV = -\beta \cdot DT - R_s \cdot DI \tag{5}$$

$$DT = T - T_{ref} \tag{6}$$

Where, D is the duty cycle of diode switch; is the reference value of the light intensity under the standard environment $1000W/m^2$; T_{ref} is the temperature reference value of photovoltaic cell, the value is $25^{\circ}C$; α is the current variation temperature coefficient of photovoltaic cells in standard environment; β is the temperature coefficient of voltage variation of photovoltaic cells in standard environment.

2.2 Photovoltaic cell simulation research

According to the given mathematical model of solar photovoltaic cell, the simulation model of photovoltaic cell is built in MATLAB / Simulink platform. Figure 2 shows the photovoltaic cell simulation model built in Simulink[3].

The parameters of photovoltaic cells under standard conditions are: open circuit voltage U_{oc}=37.1V. Short circuit current I_{sc}=8.18A. Current at maximum power point I_m=7.65A. Voltage at maximum power point U_m=29.9V. Maximum output power P_m=228.7W. The output characteristic curves of photovoltaic cells under different illumination intensity and different ambient temperature are analyzed.

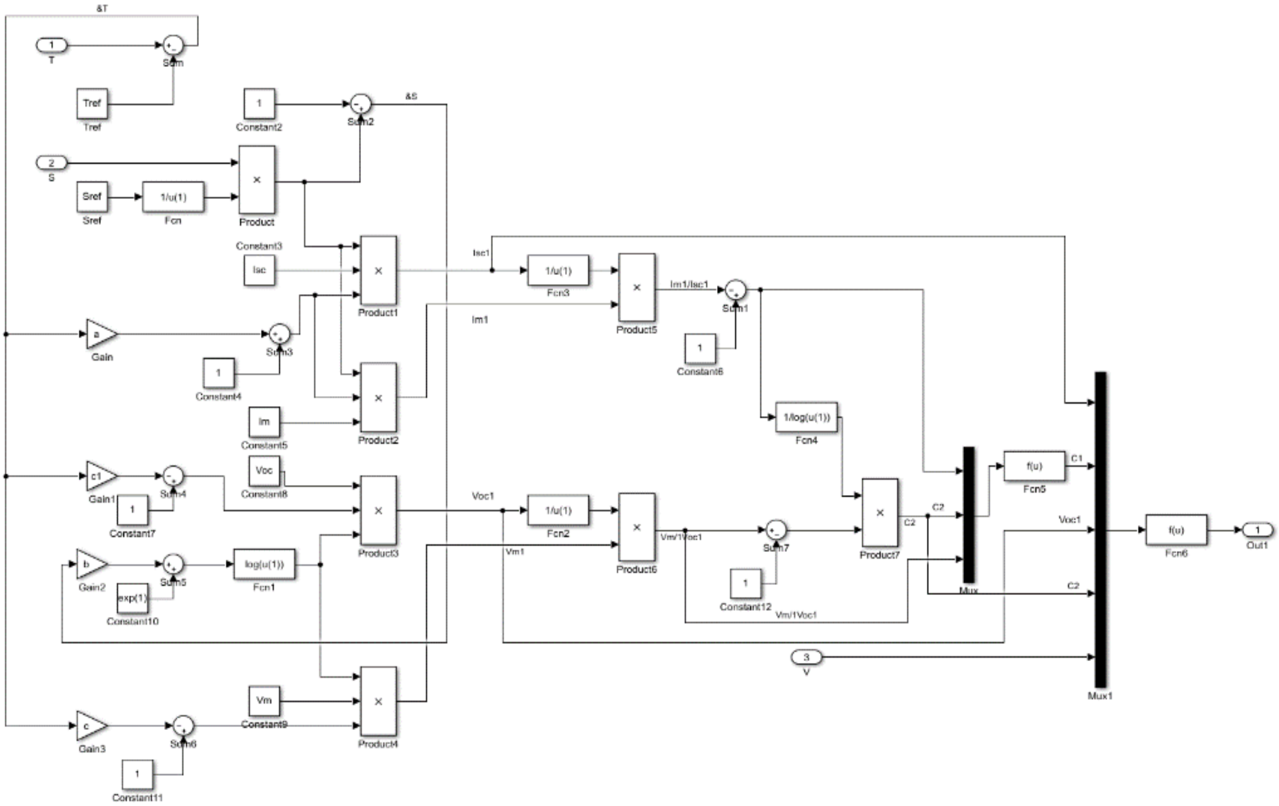

Figure 2. Photovoltaic cell simulation model

When the ambient temperature is $25^{\circ}C$, simulation of photovoltaic cells in different light intensity output characteristic curve is shown in Figure 3. When the light intensity is $1000W/m^2$, simulation of photovoltaic cells in different ambient temperature P/V output characteristic curve is shown in Figure 4.

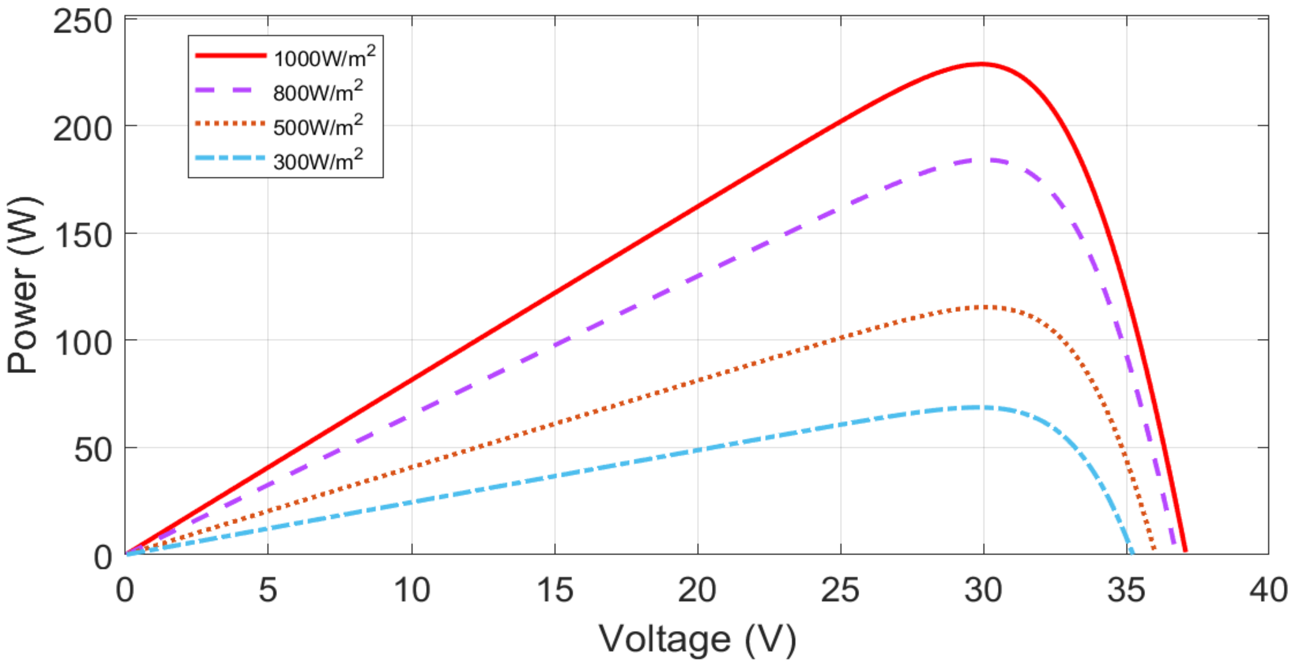

Figure 3. Performance of photovoltaic cells under different light intensities P/V Output characteristic curve

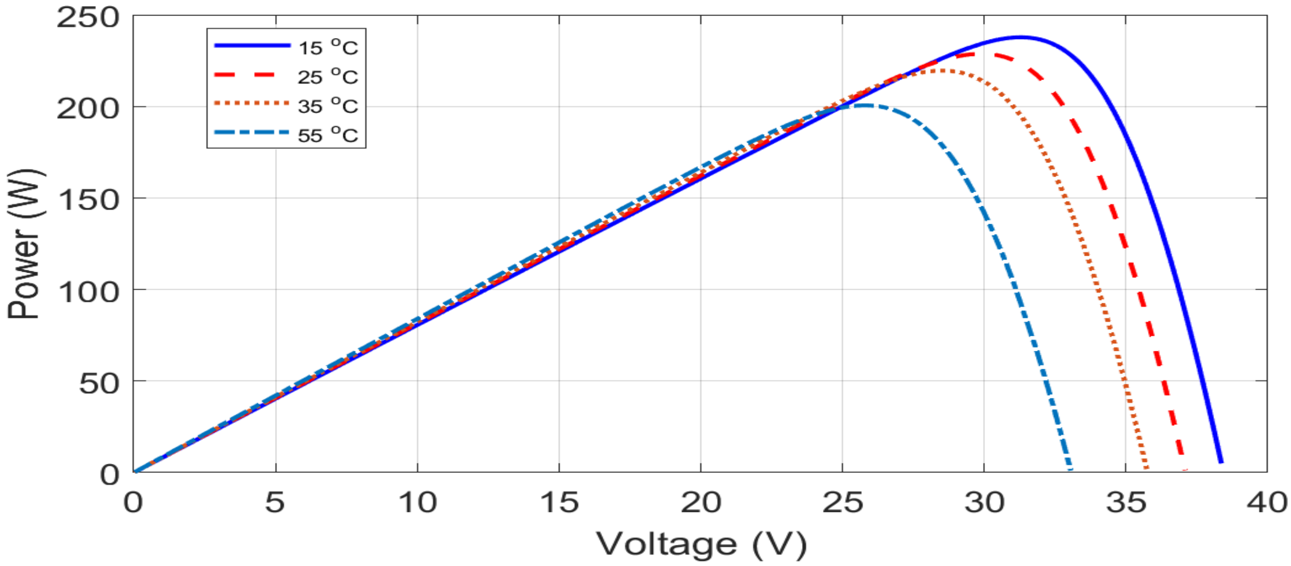

Figure 4. Performance of photovoltaic cells at different ambient temperatures P/V Output characteristic curve

According to the P/V characteristic curve from Fig. 3 and Fig. 4, the maximum power point of photovoltaic cells has changed significantly when the light intensity is changed when the external temperature is constant and the temperature is changed when the external light intensity is constant. That is, the external environment temperature and illumination intensity have an impact on the output characteristics of photovoltaic cells, especially the power output of photovoltaic cells. We hope to obtain enough power from photovoltaic cells. Therefore, how to control the photovoltaic cells to work at the maximum power point is a problem worthy of in-depth study.

3. MPPT control principle

When the photovoltaic cell works normally, its internal resistance will change with the change of external light intensity and temperature P/V characteristic curve will also move, and photovoltaic cells can not always maintain the maximum power output by itself. In order to maximize the utilization of photovoltaic cells, it is necessary to control the photovoltaic cells to work at the maximum power point, that is, MPPT control of photovoltaic cells[4]. The MPPT control principle is shown in Figure 5. By adding impedance converter between photovoltaic cell and power load, MPPT algorithm is used to control the impedance converter in real time, and adjust duty cycle of the DC/DC converter, ensures that the equivalent load after transformation is always equal to the internal resistance of the photovoltaic cell, so that the photovoltaic cell can always output the maximum power[5].

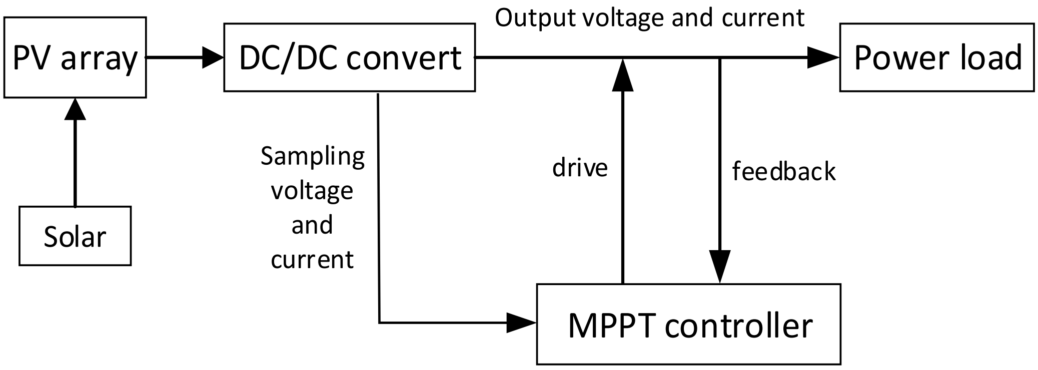

Figure 5. MPPT control schematic diagram

4. MPPT control algorithm

4.1 Incremental conductance method

The incremental conductance method is a widely used MPPT control method at present[6]. According to the relationship between the conductance and the conductivity change rate when photovoltaic cells work at the maximum power point, a control algorithm is proposed P/V According to the output characteristic curve, on the left side of the maximum power point, at the corresponding position and on the right side of the maximum power point, there are $dP/dU < 0$, $dP/dU = 0$, $dP/dU > 0$, The instantaneous power output by photovoltaic cells is $P = UI$. At the same time, the output voltage We can get the following results:

$$\frac{dP}{dU} = \frac{d(UI)}{dU} = I + U\frac{dI}{dU} \tag{7}$$

When the photovoltaic cell works at the maximum power point, it meets the following requirements:

$$\frac{dI}{dU} = -\frac{I}{U} \tag{8}$$

The control flow chart and simulation model of incremental conductance method are given in Fig. 6 and Fig. 7 respectively. In practical application, it is usually used $\Delta I/\Delta U$ To replace dI/dU From this, we can conclude that the judgment basis of the maximum power point of the incremental conductance method is as follows:

When $\frac{\Delta I}{\Delta U} > -\frac{I}{U}$ the photovoltaic cell works on the left side of the maximum power point, the maximum power point can be achieved by increasing the output voltage;

When $\frac{\Delta I}{\Delta U} = -\frac{I}{U}$ photovoltaic cells work at the maximum power point;

When $\frac{\Delta I}{\Delta U} < -\frac{I}{U}$ the photovoltaic cell works on the right side of the maximum power point, the maximum power point can be achieved by reducing the output voltage.

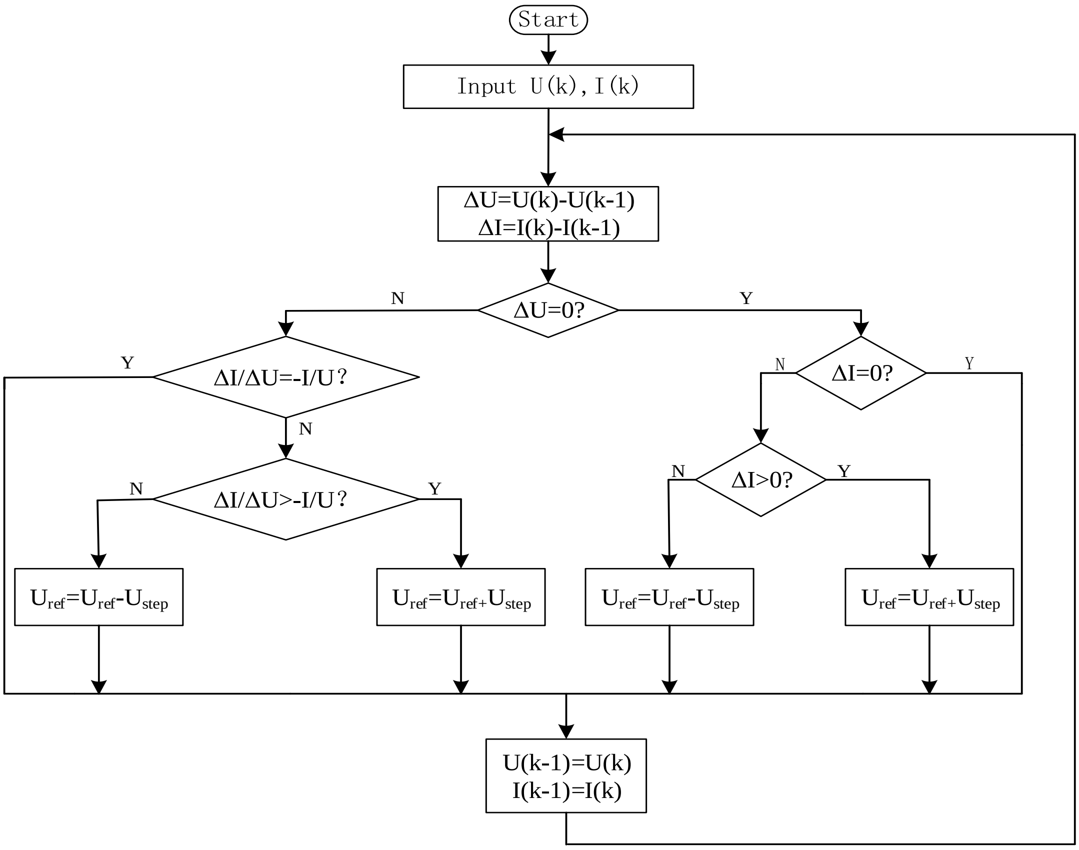

Figure 6. Control flow chart of conductance increment method

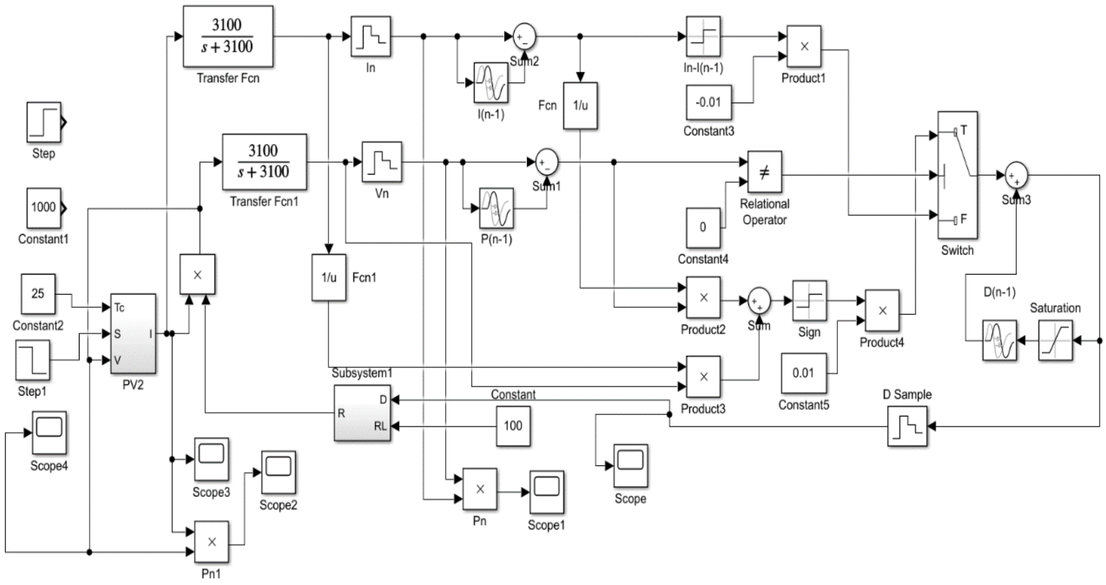

Figure 7. Simulation model of incremental conductance method

4.2 Combination algorithm

Fuzzy control is the product of the combination of fuzzy system theory and automatic control technology, which is very suitable for complex nonlinear system. Photovoltaic system is a strong nonlinear system, so the tracking method of fuzzy control is also very reliable[7]. The fuzzy control block diagram is shown in Fig. 8, and the difference between the change value of the output conductance of the photovoltaic cell and the instantaneous conductivity value is calculated $E(k)$ And this value $\varDelta E(k)$ It is defined as input variable and output variation is duty cycle D, expressed as[8]:

$$E(k) = dI/dU - (-I/U) \tag{9}$$

$$\Delta E(k) = E(k) - E(k-1) \tag{10}$$

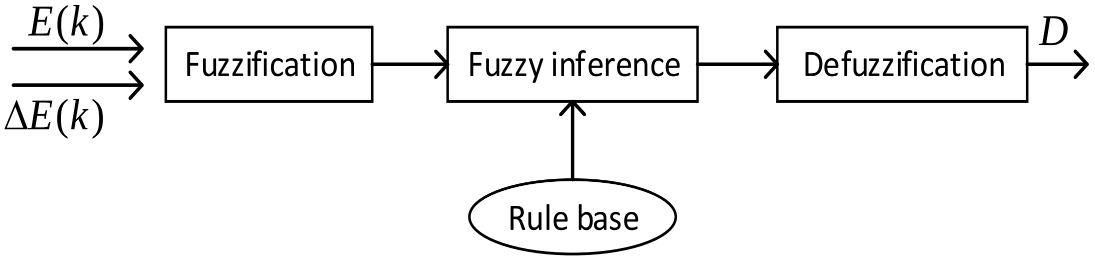

Figure 8. Fuzzy control block diagram

The input and output transform quantities are defined as seven fuzzy subsets, which are NB (negative big) NM (negative middle) NS (negative small) Z (zero) PS (positive small) PM (positive middle) PB (positive big), and change the language variable $E(k)$ and $\varDelta E(k)$ There are seven levels of discourse.

$$E(k) = \{-3,-2,-1,0,1,2,3\} \tag{11}$$

$$\Delta E(k) = \{-3,-2,-1,0,1,2,3\} \tag{12}$$

Input variables $E(k)$ and $\varDelta E(k)$ The same membership function is selected[9], z and s functions are selected on both sides, trigonometric function is selected in the middle part, and Gaussian function is selected for membership function of output variable U, as shown in Fig. 9.

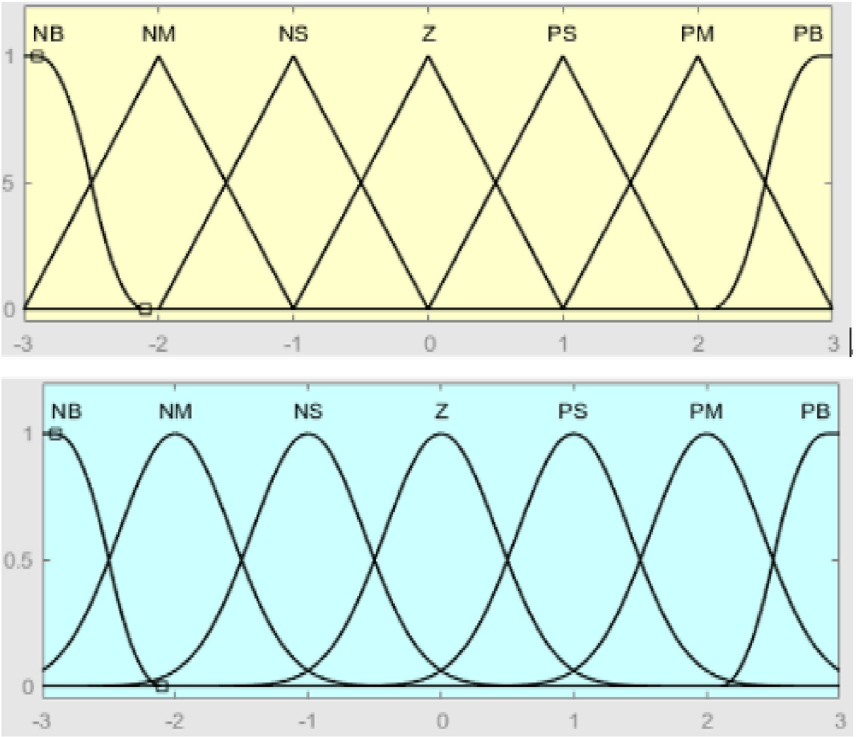

Figure 9. Membership function of fuzzy control

In order to make the system have better control effect, according to the input variables $E(k)$ and $\Delta E(k)$, The fuzzy rule table as shown in Table 1 is established[10]. If the output power of photovoltaic cell decreases due to the change of external environment, the output power can quickly return to the maximum power point according to the fuzzy rule table.

Table 1. Fuzzy rule table

CE	E						
	NB	NM	NS	Z	PS	PM	PB
NB	Z	Z	Z	NB	NB	NB	NM
NM	Z	Z	Z	NS	NM	NM	NM
NS	NS	Z	Z	Z	NS	NS	NS
Z	NM	NS	Z	Z	Z	PS	PM
PS	PS	PM	PM	PS	Z	Z	Z
PM	PM	PM	PM	Z	Z	Z	Z
PB	PB	PB	PB	Z	Z	Z	Z

In this paper, a combined algorithm based on conductance increment method and fuzzy control is proposed to achieve better MPPT control effect. When the photovoltaic system works at both ends of the P-V curve, that is, when the output power reaches 90% or less of the peak power, the incremental conductance method is used to track MPP. When the PV system works near the maximum power point of the P-V curve (the output power reaches more than 90% of the peak power), the algorithm is quickly switched to the fuzzy control method for tracking. The simulation model is shown in Figure 10.

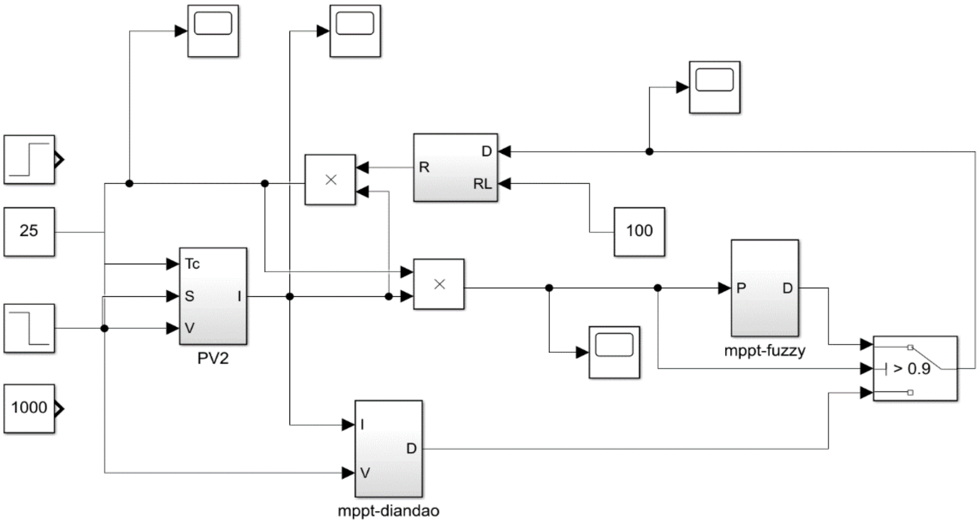

Figure 10. Simulation diagram of combined algorithm

5. Simulation analysis

In order to reflect the advantages of the combined algorithm, the two control methods are simulated under the parameters shown in Table 2. In the simulation time of 0.05 seconds, the temperature is maintained25$^\circ C$at 0.02s, the light intensity changes from 0.02s $1000W/m^2$ reduced to $800W/m^2$. The power output curves of incremental conductance method and combined algorithm are shown in Figure11 and Figure12.

Table 2. Parameter setting of photovoltaic cell

Parameter name	Parameter value	Parameter name	Parameter value
Open circuit voltage V_{oc}	170V	Step size	0.00005s
Short circuit current I_{sc}	8.5A	Simulation algorithm	Fixed-step/ode3
Mppt voltage V_m	140V	Simulation time	0.05s
Mppt current I_m	8A	Standard light intensity S	1000W/m2
Load resistance	100Ω	Standard temperature T	25°C

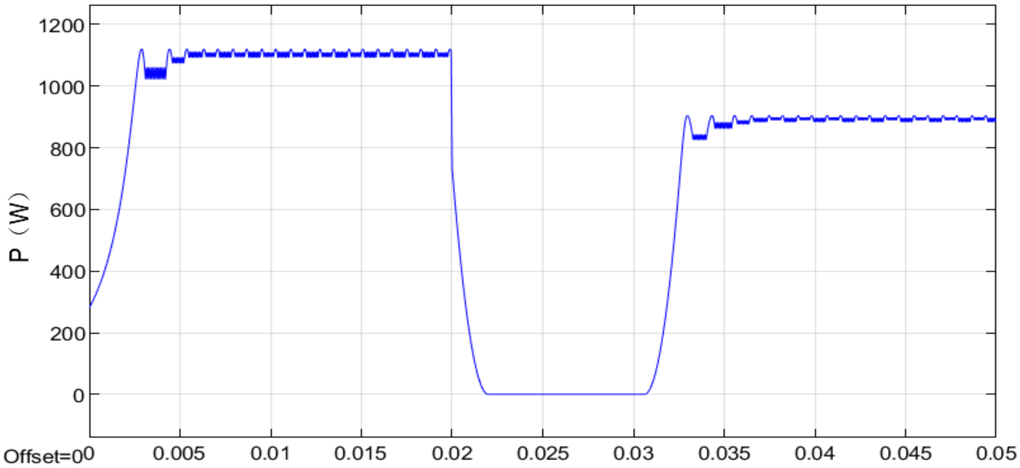

Figure 11. Output of conductance increment method

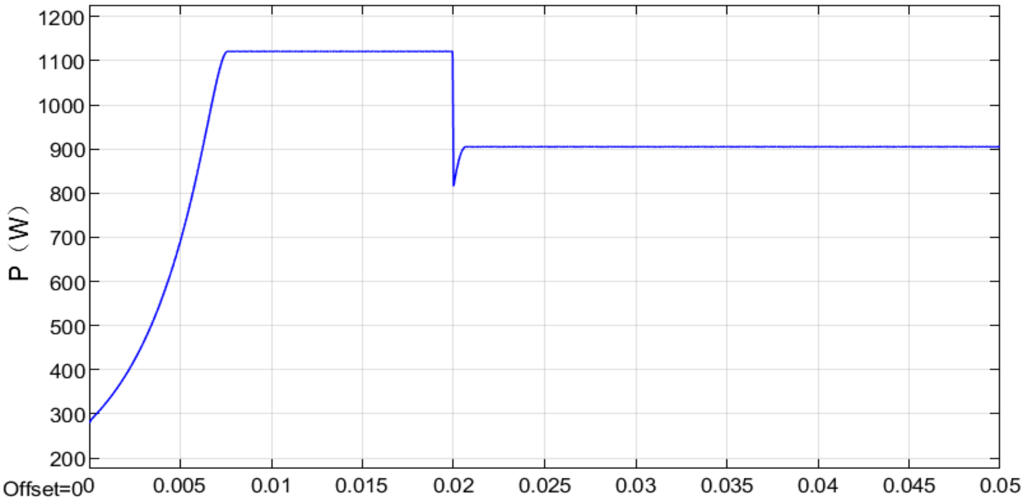

Figure 12. Output results of combined algorithm

From the simulation results, it can be seen that when the light intensity changes from $1000W/m^2$ Reduced to $800W/m^2$ It takes 0.014 seconds for the incremental conductance method to track the maximum power, while the combined algorithm only needs 0.0015 seconds to track the maximum power point; and when the maximum power point is tracked by the incremental conductance method, the error is 8W, and the error is only 2W when using the combined algorithm. This method can improve the rapidity of the control system, reduce the steady-state error of the control system, and improve the overall dynamic and steady-state performance of the photovoltaic power generation system.

6. Conclusion

This paper focuses on the maximum power point tracking control method of photovoltaic power generation. Firstly, the simplified mathematical model of photovoltaic cell is given, and the simulation model is established on the Simulink platform. The control principle of MPPT is analyzed, and the simulation model of incremental conductance method and combined algorithm is built. Through the simulation of the two methods and comparing the output results, it can be concluded that the optimization speed of the combined algorithm is almost the same as that of the incremental conductance method. However, when the external light intensity changes, the speed of the combined algorithm to stabilize the system is much faster than that of the incremental conductance method, and the error when reaching the maximum power point is also smaller. Therefore, the combination algorithm based on conductance increment method and fuzzy control has better dynamic performance and steady-state performance.

Acknowledgments

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